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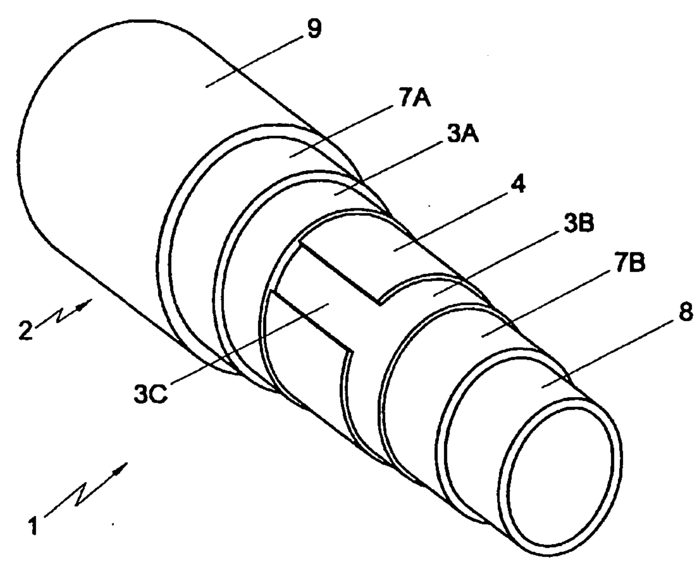
(54) Title: A COMPOSITE TUBE WITH EMBEDDED POWER CONDUCTORS



(57) Abstract: A spoolable tube (1) for use inserted in or connected to a bore hole in the ground has a tube wall (2) having at least one axially extending circumferential layer of composite material (3) and at least one longitudinally extending electric power conductor (4) embedded in the tube wall (2) and formed by a flexible, strip-like element (4) including a plurality of electrically conductive filaments (6). By configuring the conductor as a strip-like element, the cross-sectional area of the element in the tube wall (2) can be relatively large. The plurality of conducting filaments (6) provide the conductor with a structure capable of accommodating to relatively large temporary deformations of surrounding material which occur during spooling of the tube (1) to a relatively small radius.

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Title: A composite tube with embedded power conductors

The present invention relates generally to a composite tube for use inserted in or connected to a bore hole in the ground, such as in the exploration and the winning of oil and gas.

Composite tubing, in particular composite tubing capable of being spooled upon a reel, is commonly used in numerous well operations, including running wire line cable down a lithosphere bore hole with well tools, working over wells by delivering various chemicals down hole and performing operations on the interior surface of the drill hole. The spoolable composite tubes can be used in conjunction with one well and can then be transported on a reel to another well location. The composite materials used comprise reinforcing fibers, such as carbon, glass or aramid, and a matrix material, such as a thermoplastic or thermosetting polymer, supporting the fibers.

Compared to steel tubing, composite coiled tubing has increased corrosion and fatigue resistance, combined with a high strength to weight ratio.

A recent development in composite tubing is to embed electric power conductors within the wall thickness of the composite tube to enable the use of electrically powered devices suspended on or attached to the tube. In addition, data transmission is possible by superimposing a data signal on the power conduit.

Spoolable composite tubing comprising embedded power conductors as well as methods for their manufacture and the uses of such tubes in bore holes are disclosed in US 5 921 285 and WO 99/19653.

A problem associated with composite tubes with embedded power conductors is to embed a power conductor capable of conducting relatively large amounts of electrical energy in the tube wall without significantly compromising dimensions, strength, flexibility or structural integrity of the tube.

In particular, to supply sufficient power to an electric drilling motor, a submersible pump or an electric tractor, typically three copper electrical conductors are needed each having a cross sectional area of 35-40 mm^2.

Such a conductor must be integrated in the tube wall without significantly decreasing its inner diameter and/or significantly increasing its outer diameter. Decreasing the inner diameter leads to a decrease of the area provided for fluid transport, while an increase in the outer diameter increases the dimension of a spool on which the tube is coiled, thus leading to transportation problems. Furthermore, increasing the outer diameter is often not desirable in view of the limited cross-sectional area of the bore hole.

It is an object of the present invention is to provide a spoolable composite tube having power conductors embedded in the tube wall capable of transmitting sufficient power for at least one downhole electric power tool such as a downhole electric drilling motor, an electric submersible pump or an electrical tractor, without significantly compromising its dimensions, strength, flexibility or structural integrity and particularly its ability to be bent to a small radius without being permanently deformed or damaged otherwise.

This object is achieved by providing a tube according to claim 1.

By configuring the conductor as a strip-like element, the cross-sectional area of the element in the tube wall can be relatively large. The plurality of conducting filaments provide the conductor with a structure capable of accommodating to relatively large temporary deformations of surrounding material which occur during spooling of the tube to a relatively small radius.

The capability of accommodating to relatively large temporary deformations of the tube wall is markedly improved if each of the conductive filaments is at least partially oriented at an angle relative to the strip-like element of which it is a member. Thus can for instance be accomplished by arranging the

The capability of accommodating to deformations of the tube and the ease of assembling the composite structure of the tube are further enhanced if

the conductive filaments are braided, intertwined or braided and intertwined. A braided and/or intertwined structure of the strip-like elements also provides the advantage that the filaments are bundled so that handling of the strip-like element or elements before integration in the tube wall is facilitated.

The filaments can for instance be interwoven separately, but can also be interwoven as strands.

The strip-like element may comprise both electrically conductive filaments and electrically non-conductive filaments. The conductive and the non-conductive filaments can be interwoven.

The strip-like elements configured as flattened braids embedded in the tube wall thus provide a relatively large cross-sectional conductive area that can be arranged in the tube wall with a minimum impact on its dimensions, strength and wear-resistance. In particular, the easily deformable structure of the braids provide for low deformation of the conductor filaments in the tube wall when the tube is bent.

Preferably, the strip-like elements comprise a flattened tubular structure of crossingly interwoven strands of electrically conductive filaments, e.g. copper wires.

Although the longitudinally extending strip-like elements can be arranged in many configurations along at least a part of the tube's length, such as helically, as a sequence of S-turns or forming a zigzag pattern, the strip-like elements are preferably oriented substantially parallel to the tube axis. Thus, the strip-like elements form a balanced composite structure so that that tensile, flexural and pressure loads exerted thereon do not induce torsional loads exerted onto the tube.

The concept of the electric power conductor embedded in the tube wall being formed by a flexible, strip-like element comprising a plurality of electrically conductive filaments is of particular advantage if at least two of the power conductors are included in the tube wall and positioned mutually spaced in circumferential sense of the tube. This because considerations

regarding occupied cross-sectional area and mutual insulation are of particular importance if a plurality of power conductors is required.

By providing three strip-like elements, the elements having substantially equal dimensions and being distributed substantially equally along the circumference of the tube wall, it is achieved that the tube has equal bending stiffnesses in all directions.

By arranging the strip-like elements to curvedly extend along a part of the circumference of the tube wall, it is achieved that the elements can be accommodated in a circumferential layer of the tube wall. Preferably, the strip-like elements or braids are curved substantially concentrically to the tube axis. This way, the radial thickness of a layer comprising the braids can be minimized.

By embedding the strip-like elements in a circumferential layer of electrically non-conductive composite material it is achieved that the layer containing the braids can add to the structural strength of the tube. This way, the impact of the embedded conductors on the structure of the tube can be further reduced.

Such a non-conductive composite layer can also comprise an axially extending circumferential layer of electrically non-conductive composite material covering the strip-like elements on the outside and/or the inside, while the circumferential area between the strips is filled with a composite or a non-composite material, e.g. the matrix material of the composite material of the covering layers. This way, the electrically non-conductive layer with embedded strips can be manufactured relatively easily, e.g. by means of the thermoplastic tape winding process. It is also possible to provide that the electrically non-conductive layer inside of the strips also forms the inner liner.

By impregnating the strip-like elements with non-conductive material, e.g. with the matrix material also included in the electrically non-conductive layers, bonding between the surrounding non-conductive, insulating layers can be increased. Preferably the matrix material is applied by pre-impregnating

before bringing the strip-like elements in the intended position. In addition voids in the braids can be reduced and mechanical and electrical behaviour can be improved. By using a thermoplastic material, the conductors can be manufactured in the same way as composite tapes, which facilitates manufacturing the tube by means of the thermoplastic tape winding process.

By providing the tube with a pressure resistant, inner tubular liner the pressure resistance of the tube can be increased. Such a tubular liner can conveniently be used as a mandrel on which the composite layers are wound. Preferably, such a tubular liner comprises a non-composite, thermoplastic material.

Use of thermoplastic material in the tube wall allows local plastic deformation of the tube wall resulting in cracks being closed or evening out of other stress or wear-induced damage, in particular under influence of heat and/or incidental large deformation.

Further advantageous embodiments are discussed in the appended claims.

The invention will be further elucidated using an example shown in a drawing. In the drawing:

Fig. 1 is a cross-sectional view of a composite tube;

Fig. 2 is a perspective view of the tube of Fig. 1;

Fig. 3 is a perspective, partially cut away view of a connector-coupler assembly for connecting the tubes end to end;

Fig. 4 is a longitudinal, cross-sectional view of a detail of the connector of Fig. 3;

Fig. 5 is a schematic side view representing an operating sequence in which a tube as described is employed;

Fig. 6 is a schematic side view showing use of a tube as described for retrieving an object from a bore hole; and

Fig. 7 is a schematic side view showing use of a tube as described as a riser with integrated power conductors for controlling a subsea unit.

The drawings only serve as non-limiting elucidations of a preferred embodiment of the invention. In the drawings, identical parts are denoted with the same reference numerals.

Figs. 1 and 2 show a composite tube 1. The tube comprises a tube wall 2 having a number of circumferential layers axially extending along central axis A of the tube 1 in a laminar fashion.

The tube wall 2 comprises a central layer 3 of electrically non-conducting composite material. The non-conducting layer of composite material comprises a thermoplastic matrix material, e.g. polyetherimide (PEI), polyphenylene sulfide (PPS), polyetheretherketone (PEEK), polyvinylidene fluoride (PVDF), polyethersulfone (PES), polysulfone (PSU), polyethylene terephthalate (PET), polyamideimide (PAI), polyurethane (PUR), polyamide (PA), polypropylene (PP) or polyimide (PI), reinforced with fiberglass or other fiber materials. The specific selection of materials will typically be governed by operating conditions and other application dependent requirements the tube will have to fulfil.

Embedded in the electrically non-conductive layer are three electric power conductors, each extending substantially parallel along the tube axis A. The power conductors are each formed as a flexible strip-like element 4 comprising a plurality of electrically conductive, braided filaments. The strip-like elements are formed as flat braids wherein strands 5 of copper wires 6 (fig. 1) that axially extend along axis A are arranged in a crossing fashion. The angle between the axis of the strip and the axes of the conductive elements therein is preferably between 15° and 70° and preferably between 35° and 55°.

The flat, strip like elements 4 each have substantially equal dimensions and are distributed substantially equally along the circumference of the tube wall 2. Depending on the diameter of the tube and the required conductive cross-sectional area, the thickness to width ratio of the strips is preferably between about 1:50 and about 1:3 and most preferably between about 1:20 and about 1:5.

Each element 4 is substantially flat and extends curvedly along a part of the circumference of the tube wall 2, the curvature being substantially concentrically to the tube axis A.

The electrically non-conductive composite layer 3 wherein the flexible, strip-like elements are embedded is composed of a radially outwardly and a radially inwardly disposed covering layer 3A, 3B covering the interposed strip-like elements 4, which are contained in an intermediate layer 3C. The covering layers 3A, 3B comprise a thermoplastic matrix material having fiber reinforcements, while in this example the material of the intermediate layer 3C between the strips is a thermoplastic matrix material without fiber reinforcement. For ease of application, it can also be advantageous to provide that the material of the intermediate layer 3C between the strips is a thermoplastic matrix material including fibers, for instance in the form of pultruded strips. In the thermoplastic material the flexible, strip-like elements are embedded. The strip-like elements are impregnated with the thermoplastic matrix material.

To obtain electromagnetic shielding, the strip-like elements 4 are radially interposed between axially extending, electrically conductive composite circumferential layers 7A, 7B with carbon fibre as electrically conductive high strength material. The layers can be made electrically conductive by adding conductive particles such as carbon black to the matrix material.

The tube 2 further comprises a pressure resistant inner tubular liner 8. The liner 8 is preferably made of a non-composite thermoplastic material, such as: PEEK, PPS or PVDF, the particular choice being dependent on requirements for instance regarding operating conditions and chemical resistance. The inner liner 8 carries the radially outwardly disposed circumferential layers 7B, 3B, 3C, 3A, 7A as a mandrel.

The tube 1 further comprises an axially extending corrosion resistant and/or impact resistant, radially outer circumferential shielding layer 9. The

shielding layer is preferably formed by a composite of PPS and wear resistant material such as glass fibers.

The tube wall 2 according to the present example comprises axially extending optical fibers, schematically represented by dots 22, disposed in the electrically non-conductive layer for monitoring partial discharges generated by a voltage applied on the electrical conductive elements 4. This way, structural integrity of the insulating layers can be monitored.

Referring to Figs. 3 and 4, the tube ends 10 comprise additionally reinforced wall portions of increased radial dimension. The reinforced wall portions are used for attachment of a connector 11. The connector 11 comprises an inner portion 12 for supporting the inner surface of the tube formed by the liner 8.

The connector 11 further comprises a cover mantle 13 for covering the outer surface of the tube which can be placed onto the inner portion 12 such that the inner portion 12 and the cover mantle 13 clampingly engage end wall portion 10 of the tube 1. Preferably, the inner portion 12 and the cover mantle 13 co-operate with the tube end 10 to form an anti-slip screw joint.

The inner portion 12 comprises electrically conductive portions (not shown) electrically connecting the strip-like elements 4 to sockets 14 forming electrical coupling means.

The connector 11 is used to enable an electrically conductive, torsion resistant connection of a metal coupler 15 to the composite tube 1.

The coupler 15 comprises an inner, tubular portion 16 carrying electrically conductive strips for engagement of the sockets 14. The inner tubular portion 16 further comprises bores 18 that can be aligned with corresponding bores 19 in the inner portion 12. By providing pins through the bores 18, 19 a torsion resistant coupling can be achieved between the coupler 15 and the connector 11. The coupler 15 comprises a connecting sleeve 20 which can extend over the connector 11 to provide a protective shield and has

in inner thread engaging an outer thread of the connector 11 for axially urging the connector 11 against the coupler 15 with a pre-tension.

The coupler 15 can be used for coupling to a connector 11 of a further tube 1 or can be used to connect to drilling equipment, downhole tools or the like.

The tube 1 can advantageously be manufactured by means of the thermoplastic tape winding process, in which thermoplastic tapes of composite materials are wound onto the tubular inner liner 8 which serves as a mandrel. The thermoplastic tape-winding process is discussed more in detail in 'On-line consolidation of thermoplastic matrix composite tape using ultrasonic heating', Bullock, Daniel E. and Boyce, Joseph, 39th International SAMPE Symposium April 11-14, 1994, p 1500-1506, which publication is incorporated herein by reference.

The tube 1 can be coiled on a reel, e.g. for transportation. The tube 1 can be subsequently uncoiled from the reel and be inserted in a bore hole in the ground. The use of the tubing is discussed more in detail in 'Coiled tubing technology continues its rapid growth', Ken Newman, World Oil, January 1998, p. 64-71, which publication is incorporated herein by reference.

For spooling to a compact spool, the tube is preferably spoolable to a radius of curvature of 3 meter or smaller and preferably 2.3 to 1.8 meters or smaller at an outer tube diameter of 70 mm, i.e. to a radius of curvature of about 43 times or less, and preferably about 33-26 times or less the outer tube diameter.

As is shown in Fig. 5, in operation, if the tube is to be loaded by an internal pressure, the tube 1 is preferably spooled from a transport reel 23 onto a dispensing reel 24 having a larger diameter than the transport reel 23 before the tube is loaded with pressure. For inserting the tube 1 into the ground, the tube 1 is uncoiled from the dispensing reel 24. Thus, the tube 1 is loaded with internal pressure only while in a condition bent to the relatively large radius around the dispensing reel 24. Another advantage of using a

relatively large dispensing reel is, that during repeated on-site spooling and unspooling, the tube does not need to be bent to the relatively small radius required for road transport, so that the life span of the tube is increased.

In Fig. 6, application of the tube 1 as smart fishing string is illustrated. For this purpose, the tube 1 is equipped with a fishing tool 25 to be attached to an object to be retrieved from the bore hole 26. The tube 1 is further equipped with a load monitor 27 communicating with a load display unit 28. Because the tube 1 is relatively light, it can easily be moved up several times to obtain a reading from the load display unit indicating whether attachment to the object to be retrieved has been realized. In many applications, the light weight of the tube also makes it possible to us the force required to pull the tube string upwards as an indication whether the tube has been coupled to the object to be retrieved.

Fig. 7 illustrates yet another application of the proposed tube 1 with integrated conductors 4. The tube 1 is connected to a remote subsea unit 29 which may for instance include a pump and valves powered via a hydraulic line 30. The tube 1 and the hydraulic line 30 are connected to a production platform 31 above sea level 33 and supported by the sea bottom 32. Since the tube 1 can be flexed substantially, it is also suitable to be used as a riser, the integrated power conductors 4 obviating the need of separate, and easily damaged electric cables for controlling valves in the subsea unit 29 or, alternatively, the need of providing a plurality of hydraulic lines controlled by valves at the production platform.

It shall be clear that the invention is not limited to the preferred embodiment discussed herein. In particular, the tube wall 2 may comprise a higher or lower number of layers. Furthermore, the tube may comprise composite layers having thermoset matrix material. Furthermore, the tube may comprise two or more than three flexible strip-like conductors. Also, the strip-like elements can be covered by radially inwardly and radially outwardly disposed separate layers of non-conductive material, while the circumferential

areas between the strips are filled with a different, non-conductive material. The strip-like elements can be provided with a non-conductive cover layer.

Advantageously, the materials of adjacent layers are chosen such that they bond together. In particular, adjacent composite layers may comprise the same matrix material and/or a composite layer adjacent to a non-composite layer may comprise the material of the non-composite material as matrix material. If two layers containing different matrix materials are to be bonded to each other the bonding can generally be improved by providing an intermediate layer of matrix material blended from the matrix materials of the composite layers to be bonded.

These and other modifications will be apparent to the skilled man and are within the scope of the invention as defined in the appended claims.

Claims

1. A tube for use inserted in or connected to a bore hole in the ground, comprising a tube wall (2) having at least one axially extending circumferential layer of composite material (3) and having at least one longitudinally extending electric power conductor (4) embedded in the tube wall (2) and formed by a flexible, strip-like element (4) comprising a plurality of electrically conductive filaments (6).

2. A tube according to claim 1, including at least two of said power conductors (4) positioned mutually spaced in circumferential sense of said tube (1).

3. A tube according to claim 2, comprising three strip-like elements (4), the elements having substantially equal dimensions and being distributed substantially equally along the circumference of the tube wall (2).

4. A tube according to any one of the preceding claims, wherein each of said conductive filaments (6) is at least partially oriented at an angle relative to the strip-like element (4) of which it is a member.

5. A tube according to any one of the preceding claims, wherein said conductive filaments (6) are braided, intertwined or braided and intertwined.

6. A tube according to 5, wherein the electrically conductive filaments (6) are interwoven with electrically non-conductive filaments.

7. A tube according to any one of the preceding claims, wherein the at least one strip-like element (4) is oriented substantially parallel to the tube axis (A).

8. A tube according to any one of the preceding claims, wherein the at least one strip-like element (4) is curved in circumferential sense of said tube (1), in accordance with the circumferential curvature of the tube wall (2) portions containing that strip-like element (4).

9. A tube according to claim 8, having a central axis (A), wherein the at least one curved strip-like element (4) has a centre of curvature substantially coaxial with the tube (1) axis.

10. A tube according to any one of the preceding claims, wherein the at least one strip-like element (4) is embedded in an axially extending circumferential layer (3) of electrically non-conductive composite material.

11. A tube according to claim 10, wherein the at least one strip-like element (4) is impregnated with matrix material.

12. A tube according to any one of the preceding claims, further comprising electrically conductive composite circumferential layers (7A, 7B) of said tube wall (2) inside and outside of the at least one strip-like element (4).

13. A tube according to any one of the preceding claims, wherein the tube wall (2) comprises a corrosion resistant and/or impact resistant axially extending, radially outer circumferential layer (9).

14. A tube according to any one of the preceding claims, wherein the at least one composite circumferential layer (3) comprises a thermoplastic matrix material, preferably chosen from the group consisting of polyetherimide (PEI), polyphenylene sulfide (PPS), polyetheretherketone (PEEK), polyvinylidene fluoride (PVDF), polyethersulfone (PES), polysulfone (PSU), polyethylene terephthalate (PET), polyamideimide (PAI), polyurethane (PUR), polyamide (PA), polypropylene (PP) and polyimide (PI).

15. A tube according to any one of the preceding claims, comprising an axially extending composite circumferential layer (3) having a thermosetting matrix material.

16. A tube according to any one of the preceding claims, wherein the tube wall (2) comprises embedded partial discharge sensors (22) for monitoring partial discharges through an axially extending, insulating layer of the tube

wall (2) generated by a voltage applied to the at least one electric power conductor (4).

17. A tube according to claim 13 wherein the sensors (22) are of the fiber-optical type.

18. A tube according to any one of the preceding claims, comprising additionally reinforced wall portions at the tube ends (10).

19. A tube according to any one of the preceding claims, wherein the tube ends (10) are provided with coupling means (11, 15).

20. A tube according to claim 19, wherein the coupling means comprise a connector (11) having an inner portion (12) supporting the inner surface of the tube (1) and a cover mantle (13) covering the outer surface of the tube (1), the cover mantle being coupled to the inner portion and clamping the end wall portion of the tube (1).

21. A tube according to claim 20, wherein said inner portion comprises electrically conductive portions electrically connected to the at least one strip-like element (4).

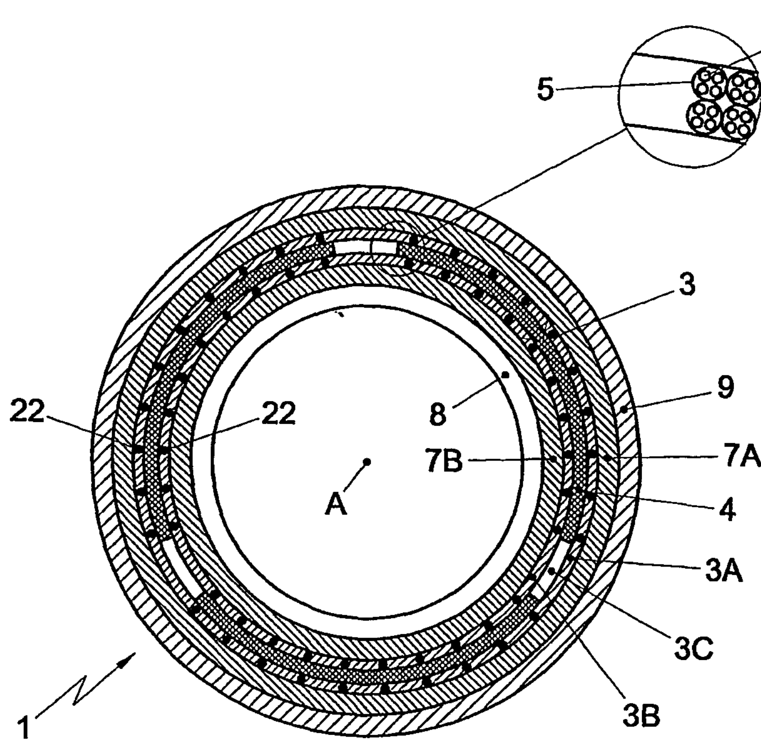

Fig. 1

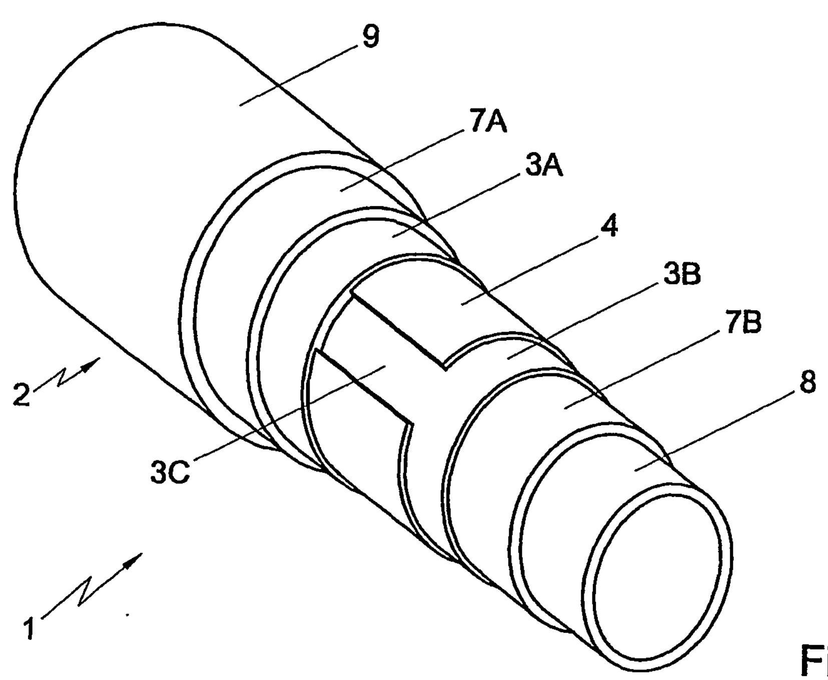

Fig. 2

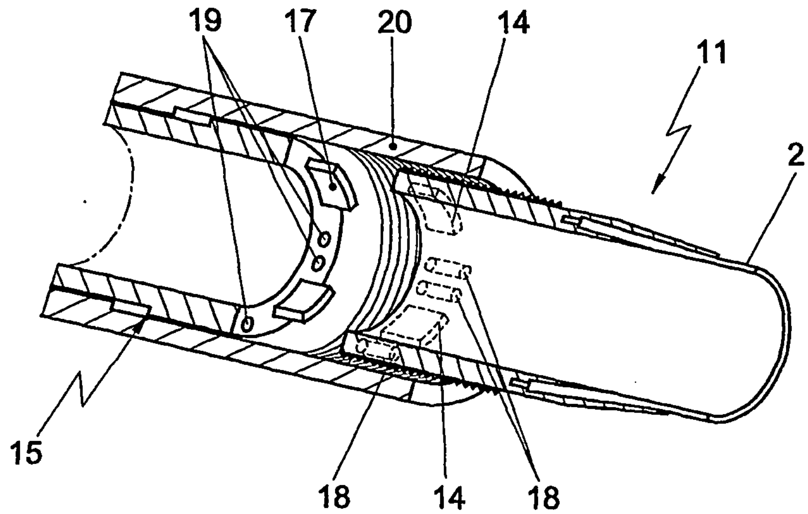

Fig. 3

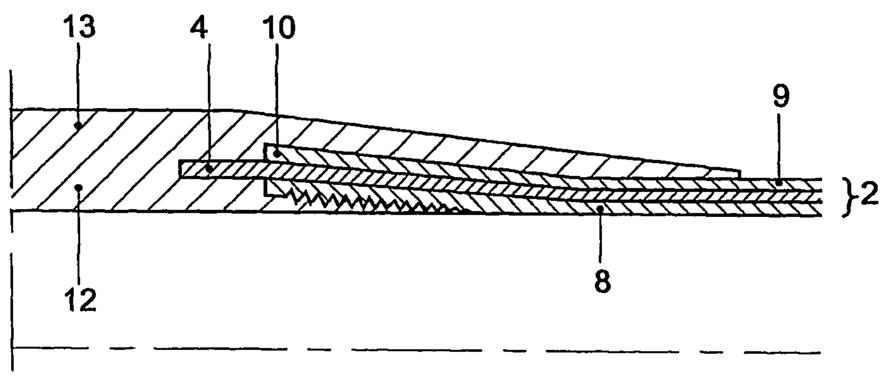

Fig. 4

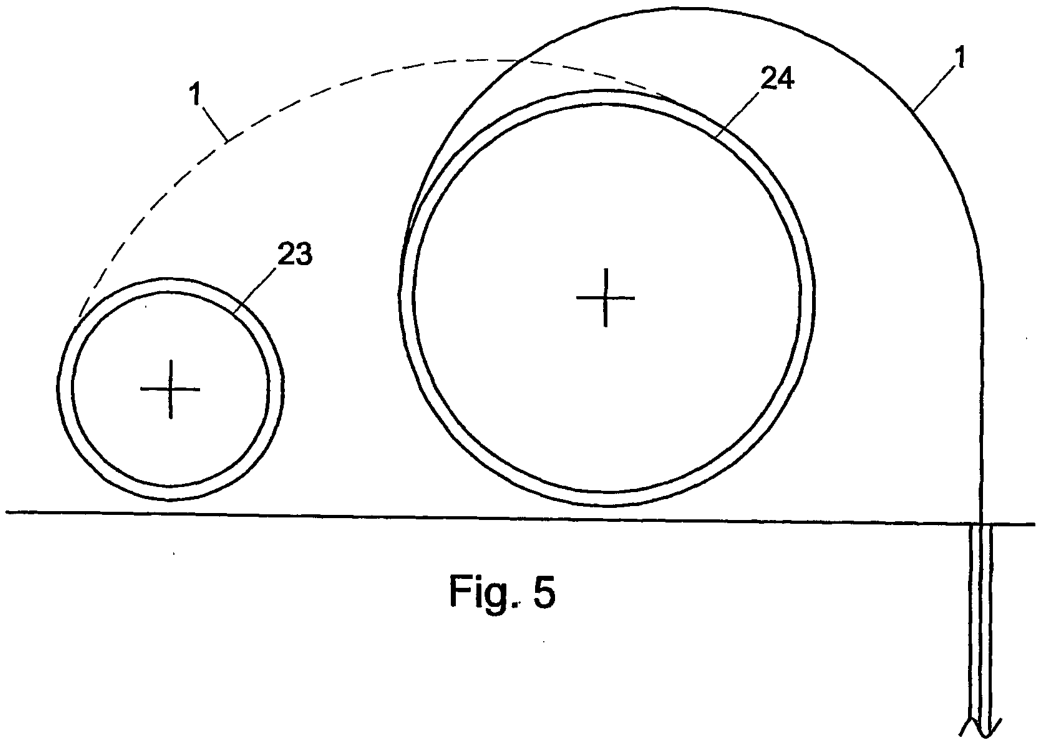

Fig. 5

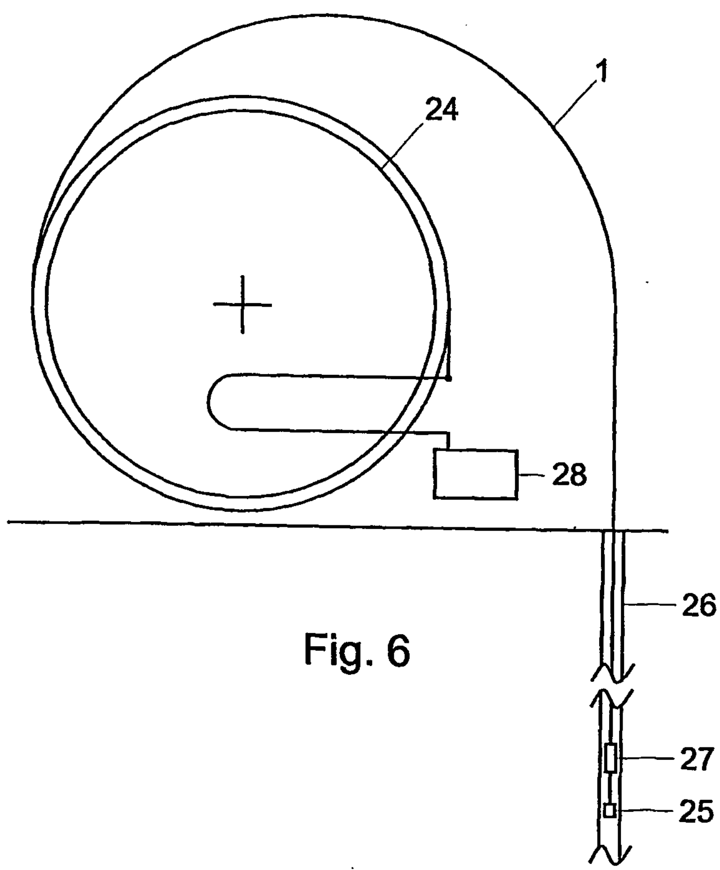

Fig. 6

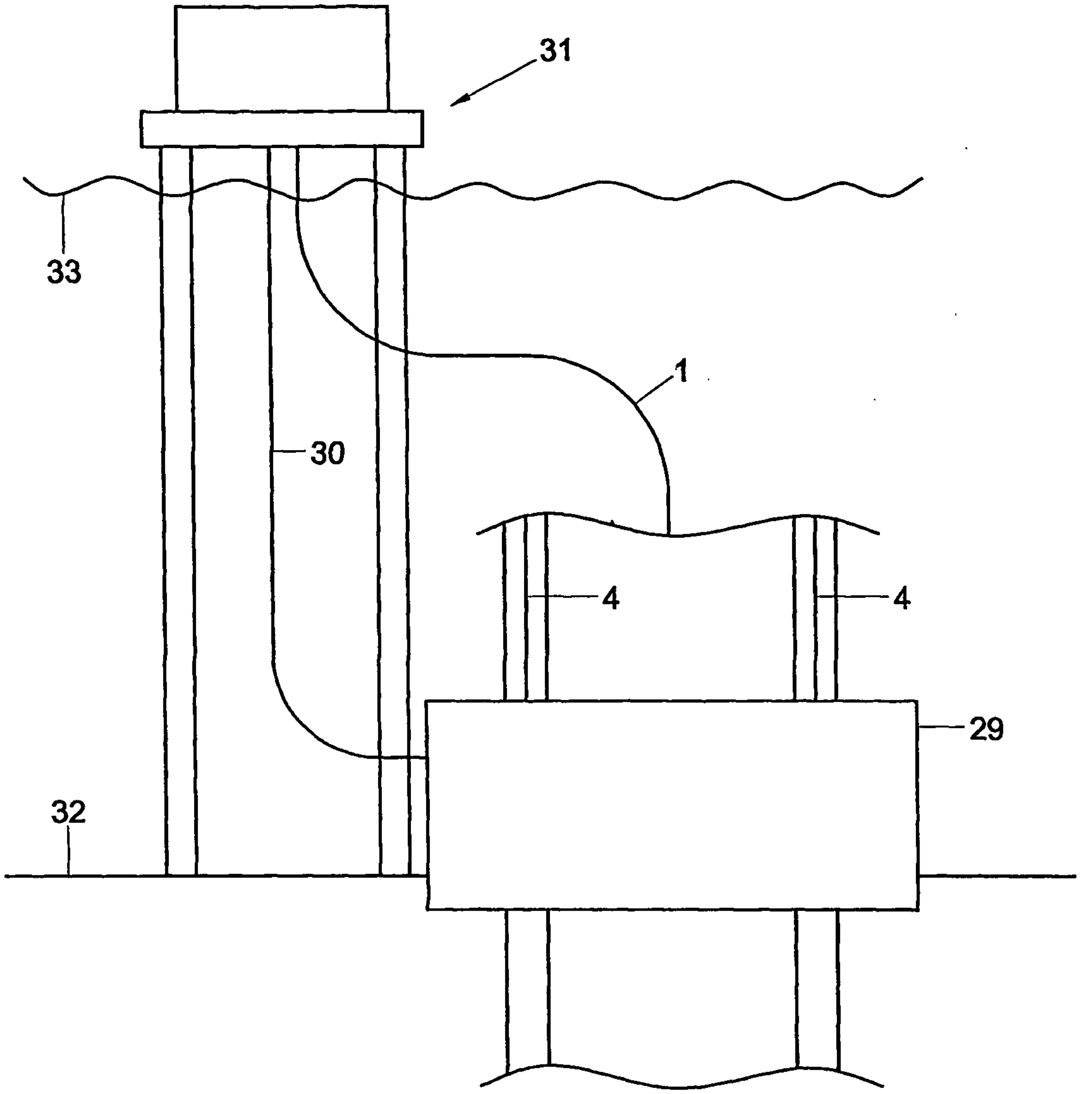

Fig. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 01/00274

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B17/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B F16L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 283 035 A (CAMCO INT) 26 April 1995 (1995-04-26)	1-3,5,8, 9,14,15, 19
A	page 7, line 24 -page 8, line 14	4,6,7, 10,11,17
	page 9, line 21 -page 10, line 5; figures 1,2,4-9; examples 12,13	
A	US 5 921 285 A (NOLET STEPHEN C ET AL) 13 July 1999 (1999-07-13) cited in the application abstract	1
A	BE 566 390 A (MOLITOR) claim 1; figures 1,2	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2001	26/07/2001

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INTERNATIONAL SEARCH REPORT

Inte... ..al Application No
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